A STUDY OF COMPARATIVE PHOSPHORUS AVAILABILITY

WITH AN AMMONIUM PHOSPHATE AND SUPERPHOSPHATE

By

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I INTRODUCTION

Availability of soil phosphorus for plant growth is of major importance in Oklahoma. Harper (23)[1] found that many soils in eastern Oklahoma were deficient of available phosphorus to the extent that the use of phosphorus fertilizers was a profitable practice for many crops. Eck and Stewart (13) reported that wheat in several areas in western Oklahoma responded to phosphorus fertilization.

Recent research (36, 38) has shown a need for both phosphorus and nitrogen fertilization in the western and central United States. The need for these two elements has brought about a greater interest in N-P fertilizer combinations. There are several products on the fertilizer market that contain both nitrogen and phosphorus as one material. These materials need to be studied as to their comparative efficiency as affected by soil characteristics, rate of application, and soil moisture conditions.

The purpose of this study was to compare an ammonium phosphate fertilizer (13-39-0) to superphosphate (20% P_2O_5) with and without urea (45% N) as to the relative effectiveness and phosphorus availability in the field and greenhouse. The treatments included potassium fertilization to study the need for nutrient element balance.

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[1] Figures in parenthesis refer to literature cited.

II REVIEW OF LITERATURE

Comparative Efficiency of Phosphate Carriers

Some of the factors influencing the comparative effectiveness of different phosphate carriers are: soil reaction, rate of application, method of application, particle size, and inherent properties of the carrier (46).

Peterson, et al. (42) reviewed and summarized the fertilizer investigations conducted in 15 western states before 1950. Phosphate carriers listed in the order of apparent availability were: 1) ordinary superphosphate, concentrated superphosphate, ammonium phosphates, and phosphoric acid; 2) calcium metaphosphate; 3) dicalcium phosphate; 4) tricalcium phosphate; and 5) rock and colloidal phosphates. Fuller (19), Robertson, et al. (44), and Schmehl, et al. (49) reported relatively the same order of effectiveness.

There were exceptions to this order under specified soil and cropping systems. Dion, et al. (10) and Mitchell (32) reported that monoammonium phosphate was superior to superphosphate on the calcareous soils of western Canada. Olson, et al. (38) found that the value of monoammonium phosphate equalled and often exceeded the value of concentrated superphosphate, both of which were equivalent to or superior to all other sources in Nebraska. Hinkle (24) reported that ammonium phosphates produced the highest yields of hay (alfalfa and sweet clover) in New Mexico. Bennett, et al. (3) reported that monoammonium phosphate was superior to superphosphate (ordinary and concentrated) on the calcareous blackland soils of Texas.

MacIntire, et al. (30) used pot cultures to compare the ammonium phosphates (mono- and di-) to superphosphate plus ammonium nitrate. They found that both monoammonium and diammonium phosphates were comparable to superphosphate on limed and unlimed cultures.

The development in the last few years of tracer technique has furnished another means of evaluation, by determining the relative phosphorus absorption, using radioactive phosphorus. Absorption data obtained by tracer techniques have rated the phosphates as follows: 1) superphosphate and ammonium phosphates; 2) calcium metaphosphate; 3) dicalcium phosphate; and 4) tricalcium phosphate (10, 40, 46, 54). This is essentially the same rating as that reported from crop yields.

The final answer for the economic evaluation of phosphorus sources must be in terms of crop yields obtained on phosphorus deficient soils when used at practical rates of application. Any early indications of differences which are not evident at harvest are only incidental.

Crop Usage and Water Solubility

The ability of applied phosphates to supply adequate phosphorus to a specific crop is determined by: 1) particle size or degree of granulation; 2) water soluble phosphorus content of the fertilizer; 3) method of application; and 4) certain soil properties, including level of available soil phosphorus, soil texture, and soil reaction.

Dion, et al. (10) found that monoammonium phosphate supplied significantly larger amounts of phosphorus to wheat than did monocalcium phosphate. In a summary of fertilization investigations in the north central United States, Fine (17) reported that the use of N-P fertilizers is important on crops such as small grains. Schmehl, et al. (49) found that monoammonium phosphate was equal or superior to superphosphate with sugar beets.

Garey (20) reported that the water soluble phosphates showed some advantage on corn and oats but were less effective on cotton. He theorized that any form of phosphate incorporated into the soil will result in a reaction with the soil, establishing an equilibrium. Those plants, such as small grains and corn, that need their phosphorus early in development, would be expected to respond best to water soluble phosphates. Those plants, such as cotton, alfalfa, and bermuda grass, that require their phosphorus over a longer period of time, may not be as affected by the form of phosphate fertilizer applied.

Norland, et al. (33) believe that the superiority of monoammonium phosphate over superphosphate under some cultural practices is attributable, in part, to the higher solubility of ammonium phosphate in the soil water. They concluded that with higher rates of application of total phosphorus, water solubility assumes greater importance for increasing yields.

Olsen (35), Smith, et al. (52), and Lawton, et al. (27) have shown that on acid soils only 40-50 percent of the phosphorus must be water soluble. Fertilizers containing a higher proportion of water soluble phosphorus stimulated earlier growth, but did not increase yield. Dion, et al. (10, 11), Olson, et al. (38, 39), and other workers (3, 17, 24, 40, 54) found that high water solubility approaching 100 percent is indicated for most fertilized crops on calcareous soils. "The ideal water soluble phosphorus content should be just enough for good growth and maximum yield without requiring a price premium." (1)

Residual Acidity and Soil Reaction

Ensminger and Pearson (16) found in Alabama that the use of monoammonium phosphate without lime resulted in decreased yields due to increased soil acidity. Monoammonium phosphate produced less than the no-phosphate check plots when lime was omitted. Ensminger (14) and Ensminger and Cope (15) reported that if dolomite was added to neutralize the acidity and if sulfur was supplied, both mono- and diammonium phosphates were about as effective for improving cotton yields as was superphosphate. Volk, et al. (56) also reported the necessity for liming and the possibility of a sulfur deficiency with the continued use of ammonium phosphates.

MacIntire, et al. (30) found the response to phosphorus from ammonium phosphates was greater on a neutral (limed) soil than on an acid (unlimed) soil. Salter and Barnes (47) reported the effect of pH on the value of ammonium phosphates as compared to superphosphate (100%) was:

pH	relative effectiveness
5.5	69%
6.0	73%
7.0	112%

These data indicate the need of liming if ammonium phosphates are used on acid soils. There is also an indication of more efficient utilization on a neutral or alkaline soil.

Nitrogen-Phosphorus Interaction

The application of nitrogen-phosphorus fertilizers usually increases the efficiency of the phosphorus uptake by the plant. Robertson and Hutton (43) and Miller and Ohlrogge (31) found that nitrogen had a greater influence on phosphorus utilization when mixed with the phosphorus rather than being placed in a separate band. Olson and Dreier (37) found that the ammonium ion was better than the nitrate ion for phosphorus enhancement.

Garey (20) stated that the early availability of phosphates aided in stand establishment and rooting. A good root system developed early should increase the drouth tolerance of the crop.

Fine (17) and Robertson, et al. (44) reported that the effect of co-joined nitrogen and phosphorus was especially important for crops, such as small grains and corn, that absorb a large part of their phosphorus in the early stages of growth. Dion, et al. (10) reported that monoammonium phosphate was recommended for wheat in Saskatchewan, Canada, for increased phosphorus utilization, even though there seems to be no response to nitrogen fertilization.

Smith, et al. (52) found that maximum yields of oats and crimson clover were not obtained until high rates of nitrogen and phosphorus were included in the fertility treatments. Fine (17) reported that the effect of increasing the rate of nitrogen was found to progressively increase the utilization of fertilizer phosphorus.

This nitrogen-phosphorus combination could be put to practical use in cases where stand establishment, rooting, or soil fixation is critical.

Residual Effects of Applied Phosphates

Only a small part of the fertilizer phosphorus applied to soils is removed by the first crop. The portion not removed should have some residual or cumulative value. The value of this residual effect can be evaluated by increased yields or increased phosphorus content of subsequent crops, soil tests for increased extractable (available) soil phosphorus, and radio-tracer technique (7, 57). The procedure of Fried and Dean (18), where differential "A" values (available soil phosphorus) are computed, offers an excellent method of studying the magnitude and duration of the effects of residual phosphates in the soil.

Factors affecting the magnitude and duration of this residual effect of applied phosphates are: 1) rate of application; 2) type of carrier; 3) soil reaction; 4) phosphorus fixation power of the soil; 5) amount of erosion; and 6) crop grown (7, 26, 28, 55). Ensminger and Pearson (16) found that the residual effect of ammonium phosphate was equal or superior to that from superphosphate.

The residual effects of applied phosphates should be taken into account when planning future fertilization, although annual applications of soluble phosphates may be necessary to obtain maximum yields from subsequent crops (29, 55).

III MATERIALS AND METHODS

Field and greenhouse experiments were established to compare the relative value of ammonium phosphate (13-39-0) to ordinary superphosphate (0-20-0) with and without urea (45-0-0). Urea was used with the superphosphate in order to give a nitrogen source comparable to the ammonium ion (NH_4^+), such as supplied with ammonium phosphate.

Description of Soil Used in the Field and Greenhouse Experiments

A Port silt loam was selected as the soil to use for these experiments. It is representative of some bottomland soils extensively used for cultivated crops in central Oklahoma. The soil for the greenhouse came from the area of the field experiment, which was located on the Lake Carl Blackwell station. The field experiment was 12 miles west of Stillwater on Highway 51, 1.6 miles north on Highway 86, and approximately 100 feet east of the highway on the W½ SW¼ NW¼ of section 11, T 19N, R 1W.

This Port silt loam is a brown to dark reddish-brown noncalcareous soil occurring on alluvium on a rarely inundated flood plain of Stillwater Creek. The area is slightly convex with about one percent slope. A complete profile description of this soil is given in Table X.

Results of some physical and chemical analyses of this soil are listed in Table I. Mechanical analysis was determined by the method

TABLE I: SOME CHEMICAL AND PHYSICAL PROPERTIES OF PORT SILT LOAM USED IN FIELD AND GREENHOUSE EXPERIMENTS.

Texture:	
Percent sand	35
Percent silt	52
Percent clay	13
Moisture equivalent	15.29%

Moisture tension data:

Tension (atmospheres)	Percent moisture
0.10	32.30
0.33	15.93
0.50	13.89
0.75	11.14
1.00	10.59
3.00	8.20
5.00	7.15
10.00	6.36
15.00	5.78

pH	6.4
Total nitrogen	0.064%
Organic matter	1.53%
Total phosphorus	0.022%
Easily soluble phosphorus	62 lbs./acre
Exchangeable potassium	250 lbs./acre
Cation exchange capacity	9.51 meq./100 gram
Percentage base saturation	78.71

Cations	Meq./100 gram	Saturation (percent)
Calcium	4.99	52.47
Magnesium	1.97	20.72
Potassium	0.32	3.36
Sodium	0.11	1.16
Hydrogen	2.12	22.29

of Bouyoucos (4). The moisture equivalent was measured by the procedure outlined by Briggs and McLane (5) and modified by Briggs and Shantz (6). Moisture tension data were determined by the methods of Richards (45), using pressure membranes.

The glass-electrode method outlined by Peech and English (41) was used in determining soil pH. Total nitrogen was determined by a modification of the Kjeldahl method described by Jackson (25). A procedure proposed by Schollenberger (50) was used for determining the percent organic matter. Total phosphorus was determined by the method outlined by Shelton and Harper (51). Easily soluble phosphorus was determined by leaching with 0.1 normal acetic acid as proposed by Harper (22). Exchange capacity was determined by the procedure outlined by A. O. A. C. (2). Exchangeable bases were determined with a Beckman flame spectrophotometer (21) with photomultiplier attachment, using an oxygen-hydrogen flame by the method outlined by Jackson (25).

Field Experimental Procedure

The statistical design used in the field experiment was a split-plot design with three replications. The field plots were 10 feet wide and 25 feet long. Potassium levels were the main plot treatments, using two levels, 0 and 40 pounds of K_2O per acre. There were seven basic treatments randomized within each main plot. These treatments are presented in Table II.

The plots were fertilized and planted to Concho wheat (48) on October 15, 1956. The fertilizer was applied in bands two inches

TABLE II: FERTILITY TREATMENTS, RATES, AND FERTILIZER MATERIALS USED IN THE FIELD EXPERIMENTS, LAKE CARL BLACKWELL STATION, 1957.

Treatment Symbol	Lbs. per acre 1/	Fertilizer Material
Check	0-0-0	No fertilizer
P_1	0-40-0	Superphosphate (20% P_2O_5)
P_2	0-80-0	Superphosphate (20% P_2O_5)
N_1P_1	13.3-40-0	Urea (45% N) + Superphosphate (20% P_2O_5)
N_2P_2	26.6-80-0	Urea (45% N) + Superphosphate (20% P_2O_5)
AP_1	13.3-40-0	Ammonium phosphate (13-39-0)
AP_2	26.6-80-0	Ammonium phosphate (13-39-0)
K_1	0-0-40	Muriate of potash (60% K_2O)

1/ Rate figures represent pounds per acre of N, P_2O_5, and K_2O respectively.

below the surface with a belt type fertilizer applicator designed to apply small amounts of fertilizer accurately. Four rows one foot wide and 20 feet long were harvested on June 25, 1957. Individual samples were threshed and the grain yield determined.

The plots were refertilized after a seedbed was prepared and Lahoma sweet sudan grass (9) was planted on July 19, 1957. An irrigation of about one and one-half inches of water was applied after seeding to aid in obtaining a uniform stand, as the topsoil was dry, although subsoil moisture was present. A sample area three feet wide by 20 feet long was harvested on October 28, 1957, for forage yield.

Greenhouse Experimental Procedure

The greenhouse experiments were established as a randomized block design with a treatment factorial of two potassium levels and nine basic treatments of combinations and rates of urea, superphosphate, and ammonium phosphate. The treatments were replicated three times at high and low moisture levels. Details of the soil fertility treatments and moisture levels are presented in Table III.

Four kilograms of Port silt loam, screened to pass a 4-mesh screen, were portioned into weighed one-gallon glazed earthenware pots. The fertilizer materials were placed in a circular band one and one-half inches below the soil surface and one inch from the pot wall. The superphosphate (0-20-0), urea (45-0-0), and ammonium phosphate (13-39-0) were fertilizer grade. These materials were screened to obtain uniform granular materials. The potassium source used was KCl (C.P.).

TABLE III: FERTILITY TREATMENTS AND MOISTURE LEVELS USED IN THE GREENHOUSE EXPERIMENTS, STILLWATER, 1958.

Fertility Treatments

Treatment Symbol	Lbs. per acre 1/	Fertilizer Material
Check	0-0-0	No fertilizer
N_1	25-0-0	Urea (45% N)
N_2	50-0-0	Urea (45% N)
P_1	0-75-0	Superphosphate (20% P_2O_5)
P_2	0-150-0	Superphosphate (20% P_2O_5)
N_1P_1	25-75-0	Urea (45% N) + Superphosphate (20% P_2O_5)
N_2P_2	50-150-0	Urea (45% N) + Superphosphate (20% P_2O_5)
AP_1	25-75-0	Ammonium phosphate (13-39-0)
AP_2	50-150-0	Ammonium phosphate (13-39-0)
K_1	0-0-100	KCl (C.P.) (60% K_2O)

Soil Moisture Levels

Low	0.5 x moisture equivalent	7.64% moisture
High	1.5 x moisture equivalent	22.93% moisture

1/ Rate figures are in equivalent pounds per acre of N, P_2O_5, and K_2O respectively.

The greenhouse experiments were separated into four studies. The objective of the first two studies was to determine the effect of the soil fertility treatments on the yield and chemical composition of Redlan grain sorghum forage (8), with differential soil moisture conditions. Details of these moisture levels are given in Table III. These soil moisture levels were selected to indicate extremes in soil moisture conditions based on previous work by Welch (58) and Nossaman (34).

The total weight of the pot and the soil at its specified moisture content was recorded for each individual pot. Moisture levels were periodically maintained by placing the pots on scales and adding sufficient water to bring the soil to its specific moisture content. The pots of the low moisture level study were initially brought up to moisture equivalent for germination of the plants. The plants at the low moisture level were allowed to wilt each time before additional water was added.

The pots were fertilized and planted to Redlan grain sorghum on December 10, 1957. Twenty seeds per pot were planted and stands were later adjusted to seven plants per pot. The plants were harvested for forage yield on February 18, 1958, when the first heads appeared.

The plants were oven dried and weighed for yield data. The samples were then ground and two samples of the forage from each pot were analyzed for chemical composition. Total nitrogen was determined by the modified Kjeldahl method outlined by Jackson (25). Samples were digested for phosphorus, potassium, calcium, and magnesium content by the wet-digestion method of Shelton and Harper (51). The total phosphorus was also determined by the procedure reported by Shelton and Harper. The potassium, calcium, and magnesium were determined with a Beckman flame spectrophotometer as reported by Jackson (25).

The second two studies were designed to measure the residual effects of the soil fertility treatments of the first two studies on the yield of Lahoma sweet sudan grass (9) forage. After the Redlan grain sorghum was harvested from the first two experiments the pots were replanted to Lahoma sweet sudan grass. The two experiments were maintained at moisture equivalent.

The pots were planted on February 19, 1958, and the stand was later adjusted to nine plants per pot. The plants were harvested on May 6, 1958, when the first heads appeared. The plants were oven dried and weighed for yield data.

Statistical Analyses

Statistical analyses were used on the yield and chemical composition data as an aid in interpretation. Coefficients of variation and analyses of variance for significant differences were determined by methods outlined by Snedecor (53). A multiple range test proposed by Duncan (12) was used as an aid in interpreting the data when significant values were obtained from the analysis of variance.

IV RESULTS AND DISCUSSIONS

Field Experiments

There were two field experiments established to study the effect of the soil fertility treatments on the grain yield of Concho wheat and the forage yield of Lahoma sweet sudan grass. The treatment symbols explained below will be used in the discussion of the results.

Treatment Symbol	Fertilizer Material	Analysis 1/	Rate (lbs. per acre)
Check	No fertilizer		--
N_1	Urea	(45-0-0)	29.6
N_2	Urea	(45-0-0)	59.2
P_1	Superphosphate	(0-20-0)	200.0
P_2	Superphosphate	(0-20-0)	400.0
AP_1	Ammonium phosphate	(13-39-0)	102.5
AP_2	Ammonium phosphate	(13-39-0)	205.0
K	Muriate of potash	(0-0-60)	66.7

Effect of Soil Fertility Treatments on the Grain Yield of Wheat:

Grain yields of Concho wheat from the field plots are presented in Table IV. There were no statistically significant yield differences between the fertility treatments as indicated by the F values from the analysis of variance. Details of the soil fertility treatments used in the experiment are shown in Table II. The yield figures

1/ Figures in parenthesis represent percent N, P_2O_5, and K_2O respectively.

TABLE IV: EFFECT OF VARIOUS SOIL FERTILITY TREATMENTS ON THE GRAIN YIELD OF CONCHO WHEAT, PORT SILT LOAM, FIELD EXPERIMENT, LAKE CARL BLACKWELL STATION, 1957.

	Replications			
Treatment 1/	I	II	III	Average
	Yield in bushels per acre			
Check	16.88	15.56	18.48	16.97
P_1	16.94	14.10	13.34	14.79
P_2	15.32	12.12	11.88	13.11
N_1P_1	23.74	16.44	16.48	18.89
N_2P_2	16.56	22.94	16.76	18.75
AP_1	15.98	20.02	17.68	17.89
AP_2	15.66	21.56	18.36	18.53
K	16.38	23.44	14.60	18.14
P_1K	16.64	24.74	14.04	18.47
P_2K	14.68	20.58	14.98	16.75
N_1P_1K	20.00	12.58	19.78	17.45
N_2P_2K	22.36	18.72	18.60	19.89
AP_1K	16.28	12.94	15.28	14.83
AP_2K	21.56	21.48	17.98	20.33

Mean Yields by Soil Treatment 2/

Treatment	K_0	K_1	Average
	Yield in bushels per acre		
Check	16.97	18.14	17.55
P_1	14.79	18.47	16.63
P_2	13.11	16.75	14.93
N_1P_1	18.89	17.45	18.17
N_2P_2	18.75	19.89	19.32
AP_1	17.89	14.83	16.36
AP_2	18.53	20.33	19.43
Average	16.99	17.98	17.49

Standard Error of Mean=3.248 C.V.=18.76% Treatment F Value (not significant)

1/ See Table II for details of soil fertility treatments.

2/ Each figure is the mean of three replications.

discussed are the average yields of three replications reported as bushels of grain per acre.

The range in differences of average yields was 7.22 bushels per acre. The lowest average yield of 13.11 bushels was from the plots which received the P_2 treatment. The highest average yield of 20.33 bushels was from the AP_2K plots. The average yield of all plots in the experiment was 17.49 bushels per acre.

The average yield of all plots which received potassium was 17.98 bushels per acre. The average yield of all plots which did not receive potassium was 16.99 bushels. Mean yields were decreased when potassium was included with the low rate of nitrogen and phosphorus (N_1P_1 and AP_1) as compared to the yield from the corresponding treatments without potassium. Mean yields were increased, however, when potassium was included with the high rate of nitrogen and phosphorus (N_2P_2 and AP_2). The lowest average yields were from the plots which received the P_1 and P_2 treatments. The highest average yields were obtained from the plots which received the high rate of a complete fertilizer treatment (AP_2K and N_2P_2K). The applications of the high rate of nitrogen and phosphorus (N_2P_2 and AP_2) produced a higher yield than the low rate when potassium was included in the treatments. These data indicate the need for favorable nutrient element balance to obtain optimum crop yields.

Monoammonium phosphate was superior in most cases to superphosphate without urea when compared at the same fertility levels. The superphosphate plus urea was superior to ammonium phosphate in three of four treatments. The average yield from the AP_2K treatment was higher than the average yield of the N_2P_2K treatment.

Effect of Soil Fertility Treatments on the Forage Yield of Sudan Grass:

Forage yields of Lahoma sweet sudan grass from the field plots are presented in Table V. Details of the soil fertility treatments used in the experiment are shown in Table II. There were no statistically significant yield differences as indicated by the F values from the analysis of variance. The treatment symbols used in this discussion are explained on page 16. The yield figures discussed are the average yield of three replications reported as tons of dry forage per acre.

The range in the differences of average yields per acre was 1.06 tons. The lowest average yield of 2.89 tons of dry forage per acre was from the plots which received only potassium (K). The highest average yield of 3.95 tons was from the plots which received the AP_2K treatment. The overall average yield of all plots in the experiment was 3.37 tons of dry forage per acre. Two treatments, P_1 and K, produced less forage than the check yield of 3.11 tons per acre.

The mean yield of all plots which received potassium was 3.38 tons of dry forage per acre. The mean yield of the plots which did not receive potassium was 3.36 tons. The application of potassium only (K) decreased the average yield by 0.22 tons as compared to the check (no treatment) plots. Mean yields were decreased when potassium was included with the low rate of nitrogen and phosphorus (N_1P_1 and AP_1) as compared to the corresponding treatments without potassium. However, mean yields were increased when potassium was included with the high rate of nitrogen and phosphorus (N_2P_2 and AP_2). When

TABLE V: EFFECT OF VARIOUS SOIL FERTILITY TREATMENTS ON FORAGE YIELD OF LAHOMA SWEET SUDAN GRASS, PORT SILT LOAM, FIELD EXPERIMENT, LAKE CARL BLACKWELL STATION, 1957.

	Replications			
Treatment 1/	I	II	III	Average
	Tons forage per acre (14% moisture)			
Check	3.96	2.35	3.04	3.11
P_1	3.68	3.38	1.93	2.99
P_2	4.03	3.44	3.11	3.52
N_1P_1	3.50	2.91	4.44	3.62
N_2P_2	3.44	4.13	2.88	3.48
AP_1	3.38	3.96	3.50	3.61
AP_2	3.02	3.27	3.18	3.16
K	2.41	3.03	3.23	2.89
P_1K	2.52	3.04	3.74	3.10
P_2K	2.44	4.46	3.13	3.34
N_1P_1K	3.26	3.84	3.17	3.42
N_2P_2K	4.08	2.97	4.09	3.71
AP_1K	2.01	2.85	4.97	3.28
AP_2K	3.04	3.74	5.07	3.95

Mean Yields by Soil Treatment 2/

Treatment	K_0	K_1	Average
	Tons forage per acre (14% moisture)		
Check	3.11	2.89	3.00
P_1	2.99	3.10	3.05
P_2	3.52	3.34	3.43
N_1P_1	3.62	3.42	3.52
N_2P_2	3.48	3.71	3.60
AP_1	3.61	3.28	3.44
AP_2	3.16	3.95	3.55
Average	3.36	3.38	3.37

Standard Error of Mean=1.124 C.V.=20.96% Treatment F Value (not significant)

1/ See Table II for details of soil fertility treatments.

2/ Each figure is the mean of three replications.

potassium was omitted from the treatments of the high rate of nitrogen and phosphorus, they produced less yield than the low rate. The AP_2K and N_2P_2K treatments produced the highest yields of any plots in the experiment. These data indicate the need for nutrient element balance, particularly with the higher rates of fertilization.

Monoammonium phosphate was superior to superphosphate without a nitrogen source in most cases when compared at the same fertility levels. Superphosphate plus urea was superior or equal to monoammonium phosphate except at the high fertility level with potassium, where the AP_2K plots produced a higher average yield than the N_2P_2K plots.

Greenhouse Experiments

There were four studies in the greenhouse experiments. Two experiments were established to study the effect of the soil fertility treatments on the yield and chemical composition of Redlan grain sorghum when grown at two extremes in soil moisture levels. The objective of the other two studies was to determine the residual effects of the previously applied soil fertility treatments on the yield of Lahoma sweet sudan grass. The previous crop had been grown at extremes in soil moisture conditions. The treatment symbols explained on the next page will be used in the discussion of the results of the greenhouse experiments.

Treatment Symbol	Fertilizer Material	Analysis 1/	Rate (lbs. per acre)
Check	No fertilizer		--
N_1	Urea	(45-0-0)	55.5
N_2	Urea	(45-0-0)	111.0
P_1	Superphosphate	(0-20-0)	375.0
P_2	Superphosphate	(0-20-0)	750.0
AP_1	Ammonium phosphate	(13-39-0)	192.3
AP_2	Ammonium phosphate	(13-39-0)	384.6
K	Muriate of potash	(0-0-60)	166.7

Effect of Soil Fertility Treatments and Low Soil Moisture on Grain Sorghum Forage:

Yield Results: Yield data of Redlan grain sorghum forage grown in the greenhouse at a low soil moisture level are reported in Table VI. There were no statistically significant yield differences between the fertility treatments as indicated by the F values from the analysis of variance. Details of the soil fertility treatments and soil moisture level are shown in Table III. The yield figures discussed are the average yield of three replications reported as grams of oven dry forage per pot.

The range in differences of average yields was 1.47 grams per pot comparing the mean forage yields between fertilizer sources, rates, and combinations. The lowest average yield of 5.33 grams was obtained from the N_1P_1 treatment. The highest average yield of 6.80 grams was from the AP_1 treatment. The overall average yield was 6.17 grams. Two treatments, N_1P_1 and N_2K, produced less than the check yield of 5.67 grams. The other soil fertility treatments produced higher mean yields than the check. The high application rate of

1/ Figures in parenthesis represent percent N, P_2O_5, and K_2O respectively.

TABLE VI: EFFECT OF VARIOUS FERTILITY TREATMENTS AND SOIL MOISTURE LEVELS ON FORAGE YIELD OF REDLAN GRAIN SORGHUM, PORT SILT LOAM, GREENHOUSE EXPERIMENT, STILLWATER, 1958.

Low Soil Moisture Level

	Without Potassium				With Potassium			
Treatment 1/	I	II	III	Ave.	I	II	III	Ave.
	Grams oven dry forage per pot							
Check	5.4	6.0	5.6	5.67	7.3	6.4	4.9	6.20
N_1	5.0	6.2	6.0	5.73	5.7	5.8	6.3	5.93
N_2	6.1	6.3	6.1	6.17	6.1	4.7	6.1	5.63
P_1	5.8	7.0	6.5	6.43	6.4	6.2	4.8	5.80
P_2	5.0	8.0	7.1	6.70	4.9	4.8	9.3	6.33
N_1P_1	5.9	6.3	3.8	5.33	5.7	6.2	5.3	5.73
N_2P_2	6.3	6.0	7.0	6.43	6.7	6.0	6.6	6.43
AP_1	7.0	6.3	7.1	6.80	6.4	6.7	6.7	6.60
AP_2	5.6	7.3	6.2	6.37	6.3	7.0	6.9	6.73
Average				6.18				6.15

Standard Error of Mean=0.5603 C.V.=15.72%
Treatment F Values (not significant)

High Soil Moisture Level

	Without Potassium				With Potassium			
Treatment 1/	I	II	III	Ave.	I	II	III	Ave.
	Grams oven dry forage per pot							
Check	12.5	11.5	10.6	11.53	11.8	10.5	13.7	12.00
N_1	9.1	8.9	11.2	9.73	9.4	11.0	9.5	9.97
N_2	8.4	9.5	10.7	9.53	13.9	7.9	11.0	10.93
P_1	12.3	10.9	13.9	12.37	9.8	12.1	8.6	10.17
P_2	12.7	13.1	14.2	13.33	13.8	8.7	13.8	12.10
N_1P_1	11.7	12.5	12.4	12.20	10.7	10.0	12.0	10.90
N_2P_2	8.6	8.8	11.5	9.63	11.6	13.1	9.2	11.30
AP_1	16.7	10.1	12.3	13.03	11.9	12.2	12.7	12.27
AP_2	12.7	14.5	14.3	13.83	9.9	12.9	14.5	12.43
Average				11.69				11.34

Standard Error of Mean=1.01 C.V.=15.20%
N, P, and AP Treatment F Value=2.69 * 2/

1/ See Table III for details of greenhouse experiment.
2/ * significant at 5% level.

the fertility treatments generally produced higher mean yields than the low application rate.

The application of potassium with the check, N_1, N_1P_1, and AP_2 treatments increased the mean yield over the same treatments without potassium fertilization. The addition of potassium with the other basic fertility treatments resulted in no difference in yield, or a decrease in yield. The application of urea at both rates (N_1 and N_2) without superphosphate produced a slight yield increase over the check when potassium was omitted. Decreases in yield were obtained, however, when potassium was included with the N_1 and N_2 treatments when compared to the potassium only (K) treatment.

The treatments of urea and superphosphate, with and without potassium (NP and NPK), produced yield decreases at the low rate and yield increases at the high rate, when the treatments without potassium were compared to the check (no fertilizer) and the treatments with potassium were compared to the potassium only (K) treatment. Increases in yield were obtained from both rates of superphosphate without a nitrogen and potassium source (P_1 and P_2), when compared to the check. The yields were decreased, however, when potassium was included as compared to the treatments without potassium.

The ammonium phosphate and potassium treatment (AP_1K) was the only treatment at the low fertility level with potassium to produce an increase in yield over the potassium only treatment. All phosphorus treatments in the high fertility level with potassium produced higher yields than the check, but the ammonium phosphate treatment produced the highest yield. These data may indicate the need for a high water soluble phosphorus source when the soil moisture level is low and the root environment near the fertilizer band may have a high salt concentration.

Influence on Chemical Composition: The Redlan grain sorghum forage grown in the greenhouse at a low soil moisture level was analyzed for the percent nitrogen, phosphorus, potassium, calcium, and magnesium. The composition data were submitted to the statistical analysis of variance tests. The results of the chemical analyses along with some of the statistical data are presented in Table VII. The multiple range tests of the chemical composition data are shown in Table XI. The treatment symbols used in the discussion of results are explained on page 22. The data discussed are averages of two subsamples analyzed from each treatment within each replication and expressed as percent composition of the dry forage.

<u>Nitrogen</u>: The F values for all treatments and basic treatments were significant at the 1% level. The range in differences of average percent nitrogen composition between soil fertility treatments was 0.25%. The lowest nitrogen composition of 1.88% was from the P_1 treatment and the highest percent nitrogen composition of 2.13% was from the N_2P_2 treatment.

The forage from the check pots contained 1.91% nitrogen. The treatments of superphosphate without urea (P and PK) generally reduced the percent nitrogen as compared to the check. The percent nitrogen of the forage was generally increased when potassium was included with a fertility treatment as compared to the same treatment without potassium.

TABLE VII: EFFECT OF VARIOUS SOIL FERTILITY TREATMENTS ON THE CHEMICAL COMPOSITION OF REDLAN GRAIN SORGHUM FORAGE, LOW MOISTURE LEVEL, PORT SILT LOAM, GREENHOUSE EXPERIMENT, STILLWATER, 1958. 1/

Treatment 2/	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
			Percent		
Check	1.91	0.205	3.12	0.285	0.537
N_1	2.05	0.226	3.01	0.282	0.547
N_2	2.06	0.211	3.12	0.272	0.558
P_1	1.88	0.201	2.79	0.275	0.528
P_2	1.89	0.292	2.85	0.269	0.540
N_1P_1	1.94	0.235	3.18	0.269	0.570
N_2P_2	2.13	0.296	3.10	0.281	0.590
AP_1	1.99	0.223	2.74	0.286	0.582
AP_2	2.11	0.361	2.85	0.272	0.555
Average K_0	2.00	0.250	2.97	0.277	0.556
K	1.94	0.205	3.21	0.279	0.545
N_1K	2.07	0.229	3.14	0.263	0.545
N_2K	2.12	0.223	3.07	0.292	0.537
P_1K	1.89	0.209	3.11	0.283	0.563
P_2K	1.95	0.320	3.18	0.254	0.508
N_1P_1K	2.07	0.224	3.06	0.296	0.572
N_2P_2K	1.97	0.267	2.90	0.274	0.533
AP_1K	2.01	0.223	2.90	0.285	0.547
AP_2K	2.08	0.337	3.17	0.250	0.523
Average K_1	2.01	0.248	3.08	0.275	0.541
Overall Ave.	2.00	0.249	3.03	0.276	0.549
F values 3/					
All treatments	3.12**	19.23**	5.14**	2.10*	2.55**
Basic treatment	5.18**	39.64**	4.87**	2.38*	2.47*
K treatment	$<$1.00n.s.	$<$1.00n.s.	12.01**	$<$1.00n.s.	5.80*
K x basic treatment	1.39n.s.	1.22n.s.	4.57**	2.05*	2.26*
Standard error of mean(x 10^3)	47.93	11.44	66.08	8.28	13.21
C.V. (%)	5.86	11.25	5.34	7.35	8.86

1/ Each figure represents the mean of six values obtained from duplicate chemical analyses on plant material from each of three replications for each treatment.

2/ See Table III for details of greenhouse treatments.

3/ ** significant at 1% level, * significant at 5% level, n.s. not significant. Analyses of variance included duplicate analyses as subsamples from the total forage obtained from each pot.

Nitrogen percentages were higher in all cases where nitrogen was a part of the fertility treatments as compared to the same treatments without nitrogen. The source of the nitrogen, whether urea or ammonium phosphate, did not seem to make much difference. Increasing the rate of nitrogen fertilization generally increased the percent nitrogen of the forage over the low rate of nitrogen application.

Phosphorus: The F values for all treatments and basic treatments were significant at the 1% level. The range in differences of average percent phosphorus composition between the soil fertility treatments was 0.150%. The lowest percent phosphorus, 0.201%, was from the P_1 treatment and the highest percent phosphorus, 0.361%, was from the AP_2 treatment.

The percent phosphorus of the forage from the check (no fertilizer) and the potassium only (K) treatments was 0.205%. The P_1 treatment was the only treatment to produce forage which contained a lower phosphorus composition than the check. The phosphorus composition of forage from treatments with the high rate of phosphorus fertilization was significantly higher than the check as shown by the multiple range test.

The high rate of phosphorus fertilization produced forage significantly higher in phosphorus composition than the low rate when like treatments were compared. The high rate of urea without a phosphorus source (N_2 and N_2K) decreased the percent phosphorus as compared to the low rate (N_1 and N_1K).

The N_1P_1 treatment produced forage which was higher in percent phosphorus than the forage from the AP_1 treatment, but they were about equal when potassium was added to the treatments. The forage from the AP_2 and AP_2K treatments contained the highest percent phosphorus of any treatments in the experiment. It appears from this data that at the higher rates of fertilization the water solubility of the phosphorus assumes greater importance when the soil moisture level is low.

There was an increase in the percent phosphorus of the forage when potassium was added with the treatments of only superphosphate (P_1 or P_2) or only urea (N_1 or N_2) as compared to the same treatments without potassium. There was a decrease in the percent phosphorus, however, when potassium was added with the treatments of nitrogen and phosphorus together (NP or AP) as compared to the same treatments without potassium.

Potassium: The F values for all treatments, basic treatments, K treatment, and potassium x basic treatment interaction were all significant at the 1% level. The range in differences of average percent potassium was 0.47. The lowest potassium composition of 2.74% was from the AP_1 treatment and the highest potassium composition of 3.21% was from the potassium only treatment.

The average potassium composition of all treatments which received potassium was higher than the average of all treatments without potassium. The forage of the check pots contained 3.12% potassium and the N_1P_1 treatment was the only treatment without potassium that was higher than the check. The forage from the pots which received the potassium only treatment contained 3.21% potassium and none of the other treatments receiving potassium was higher.

The potassium composition of the forage where potassium was added to a treatment containing urea was generally lower as compared to the same treatment without potassium. The addition of potassium to the P_1, P_2, AP_1, and AP_2 treatments increased the percent composition of the forage when the same treatment with and without potassium was compared. Increasing the rate of fertilization increased the percent potassium in all treatments except three which contained urea (NK, NP, and NPK).

The superphosphate treatments without urea produced forage which was higher in percent potassium in all cases than the ammonium phosphate treatments when they were compared at the same phosphorus and potassium rate of fertilization. The forage from the AP_2K treatment was higher in percent potassium than was the forage from the N_2P_2K treatment, but the NP treatments were higher than the AP treatments in the other three cases. The forage from the NP treatments was higher in percent potassium than the forage from the P treatments when potassium was omitted from the treatment. However, when potassium was added, the P treatments were higher than the NP treatments.

Calcium: The F values for all treatments, basic treatments, and the potassium x basic treatment interaction were all significant at the 5% level. The lowest calcium composition of 0.250% was from the AP_2K treatment. The highest calcium composition of 0.296% was from the N_1P_1K treatment.

The AP_1, N_2K, and N_1P_1K treatments were the only treatments to increase the percent calcium of the forage over the check value of 0.285%. The addition of potassium to the N_2, P_1, and N_1P_1 treatments increased the percent calcium of the forage as compared to the same treatment without potassium, but the percent calcium of the forage was reduced when potassium was added to the other treatments. Increasing the rate of fertilization generally reduced the percent calcium of the forage. The result of comparing the yields with the percent calcium of the forage shows that, in general, the higher yields of forage contained the lower percent calcium composition.

Magnesium: The F value for all treatments was significant at the 1% level, and the F values for basic treatments, K treatment, and the potassium x basic treatment interaction were significant at the 5% level. The lowest magnesium composition of 0.508% was from the P_2K treatment. The highest magnesium composition of 0.590% was from the N_2P_2 treatment.

The addition of potassium to a soil fertility treatment usually reduced the percent magnesium composition of the forage as compared to the same treatment without potassium. Increasing the application rate of the N, P, and NP treatments increased the percent magnesium of the forage, but in all treatments with potassium and the AP treatment, increasing the application rate decreased the percent magnesium of the forage.

Effect of Soil Fertility Treatments and High Soil Moisture on Grain Sorghum Forage:

Yield Results: Yield data of Redlan grain sorghum forage grown at the high soil moisture level in the greenhouse are reported in Table VI. The F value for all treatments was not significant, but the F value for the basic treatments of combinations and rates of nitrogen, phosphorus, and ammonium phosphate was significant at the 5% level. Details of the soil fertility treatments and soil moisture level are shown in Table III. The treatment symbols used are explained on page 22. The yield figures discussed are the average yields of three replications reported as grams of oven dry forage per pot.

The range in differences of average yields was 4.30 grams per pot. The lowest average yield of 9.53 grams was from the pots which received the N_2 treatment. The highest average yield of 13.83 grams was from the AP_2 treatment. The yield of the check was 11.53 grams and the overall average yield was 11.51 grams. Nine of the treatments produced more forage than the check and eight treatments produced less forage than the check.

The average yield of all treatments without potassium was 11.69 grams and the average yield of all treatments with potassium was 11.34 grams. The yield response to the addition of potassium was irregular among the basic treatments. There was a slight yield increase when only potassium was added to the soil as compared to the check. The N_1, N_2, and N_2P_2 treatments with potassium produced higher mean yields than these same treatments without potassium. The addition of potassium to the other basic treatments (P_1, P_2, N_1P_1, AP_1, and AP_2) decreased the yield.

Yields were decreased in most cases where urea was included in a treatment as compared to the same treatment without urea. Seven of the eight treatments containing urea produced lower yields than the check. The highest average yields at both fertility levels with or without potassium were produced from the pots which received the ammonium phosphate treatments, where most of the nitrogen and phosphorus are co-joined in one compound. Apparently, at the high soil moisture level monoammonium phosphate was a better source of nitrogen than urea and a better source of phosphorus than superphosphate.

Influence on Chemical Composition: The Redlan grain sorghum forage from the high soil moisture level greenhouse experiment was analyzed for nitrogen, phosphorus, potassium, calcium, and magnesium. The composition data were submitted to the statistical analysis of variance tests. The results of the chemical analyses along with some of the statistical data are presented in Table VIII. Multiple range tests of the chemical composition data are shown in Table XII. The treatment symbols used in the discussion of results are explained on page 22. The data discussed are averages of two samples analyzed from each treatment within each replication and expressed as percent composition of the dry forage.

<u>Nitrogen</u>: The F values for all treatments and the basic treatments were significant at the 1% level. The range in differences

TABLE VIII: EFFECT OF VARIOUS SOIL FERTILITY TREATMENTS ON THE CHEMICAL COMPOSITION OF REDLAN GRAIN SORGHUM FORAGE, HIGH MOISTURE LEVEL, PORT SILT LOAM, GREENHOUSE EXPERIMENT, STILLWATER, 1958. 1/

Treatment 2/	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
			Percent		
Check	1.94	0.247	2.69	0.214	0.478
N_1	2.10	0.248	2.75	0.197	0.500
N_2	2.13	0.251	2.76	0.215	0.525
P_1	1.76	0.236	2.63	0.200	0.502
P_2	1.66	0.265	2.34	0.205	0.502
N_1P_1	1.93	0.245	2.64	0.231	0.530
N_2P_2	2.24	0.320	2.81	0.208	0.523
AP_1	1.84	0.252	2.35	0.202	0.535
AP_2	1.89	0.286	2.32	0.208	0.505
Average K_0	1.94	0.261	2.59	0.209	0.511
K	1.88	0.243	2.74	0.203	0.490
N_1K	2.22	0.222	2.86	0.203	0.512
N_2K	1.83	0.251	2.79	0.189	0.485
P_1K	1.68	0.279	2.77	0.219	0.483
P_2K	1.89	0.293	2.52	0.207	0.499
N_1P_1K	2.05	0.255	2.72	0.243	0.525
N_2P_2K	1.74	0.286	2.64	0.192	0.475
AP_1K	1.59	0.220	2.44	0.204	0.508
AP_2K	1.79	0.257	2.55	0.200	0.478
Average K_1	1.85	0.256	2.67	0.207	0.495
Overall Ave.	1.90	0.259	2.63	0.208	0.505

F values 3/					
All treatments	2.63**	4.51**	12.99**	2.80**	1.79*
Basic treatment	3.26**	6.08**	22.97**	4.19**	1.95n.s.
K treatment	2.76n.s.	<1.00n.s.	13.70**	<1.00n.s.	5.77*
K x basic treatment	1.98n.s.	2.70*	2.90**	1.72n.s.	1.13n.s.
Standard error of mean($\times 10^3$)	115.80	12.10	47.43	7.91	14.22
C.V. (%)	14.96	11.45	4.42	9.31	6.93

1/ Each figure represents the mean of six values obtained from duplicate chemical analyses on plant material from each of three replications for each treatment.

2/ See Table III for details of greenhouse treatments.

3/ ** significant at 1% level, * significant at 5% level, n.s. not significant. Analyses of variance included duplicate analyses as subsamples from the total forage obtained from each pot.

of average percent nitrogen composition between the treatments was 0.65%. The lowest nitrogen composition of 1.59% was from the AP_1K treatment and the highest nitrogen composition of 2.24% was from the N_2P_2 treatment. The average nitrogen composition of the forage from all treatments was 1.90%.

The average nitrogen composition of the forage was 1.94% from the treatments without potassium and 1.85% from the treatments with potassium. The addition of potassium with the urea treatments of N and NP increased the percent nitrogen of the forage at the low rate, but decreased the percent nitrogen at the high rate when the same treatment with and without potassium was compared. Potassium decreased the percent nitrogen when it was added to the ammonium phosphate treatments. Potassium when added to the superphosphate only treatments decreased the percent nitrogen at the low rate and increased it at the high rate.

The forage from the check pots contained 1.94% nitrogen. All treatments which had ammonium phosphate as a nitrogen source were lower than the check. The five treatments which were higher than the check contained urea. The two treatments containing urea which were lower than the check were the high rate with potassium (N_2K and N_2P_2K). Apparently, at the high soil moisture level, the urea source of nitrogen was better than the ammonium phosphate source for producing forage with a high nitrogen composition. The yield data showed the opposite trend. The forage from the AP treatments was higher in percent nitrogen than was the forage from the P treatments, but the PK treatments were higher than the APK treatments.

Phosphorus: The F values for all treatments and basic treatments were significant at the 1% level. The range of differences in average phosphorus composition between the treatments was 0.100%. The lowest phosphorus composition of 0.220% was from the AP_1K treatment and the highest phosphorus composition of 0.320% was from the N_2P_2 treatment. The overall average phosphorus composition of all treatments was 0.259%.

The average phosphorus composition of the forage was 0.261% from all treatments without potassium and 0.256% from all treatments containing potassium. The forage from the check treatment contained 0.247% phosphorus and the forage from the potassium only treatment contained 0.243% phosphorus. The percent of phosphorus in the forage was decreased when potassium was included with the ammonium phosphate treatments and increased when potassium was included with the superphosphate only treatments. The N_1 treatment produced forage with higher phosphorus composition than the N_1K treatment produced, but the percent phosphorus of the forage was unchanged when potassium was added to the N_2 treatment. The addition of potassium to the superphosphate plus urea treatments increased the percent phosphorus at the low rate and decreased it at the high rate.

All treatments containing the high rate of nitrogen and/or phosphorus produced forage higher in percent phosphorus than the forage from the check. Six of the seven highest values were obtained from the treatments containing the high rate of phosphorus application.

The forage from the superphosphate and urea treatments generally contained a higher percent of phosphorus than the forage from the ammonium phosphate treatments. The superphosphate plus potassium treatments produced forage higher in percent phosphorus than did the ammonium phosphate and potassium treatments, but when potassium was omitted the ammonium phosphate treatments were higher than the superphosphate treatments.

Potassium: The F values for all treatments, basic treatments, K treatment, and the potassium x basic treatment interaction were all significant at the 1% level. The range in differences of average percent potassium between the treatments was 0.54%. The lowest potassium composition of 2.32% was from the AP_2 treatment and the highest potassium composition of 2.86% was from the N_1K treatment. The overall average percent potassium of the treatments was 0.263%.

The average percent potassium of the forage from the treatments containing potassium was 2.67% and of the treatments without potassium was 2.59%. The forage from the potassium only treatment contained 2.74% potassium and the forage from the check treatment contained 2.69% potassium. The addition of potassium to the basic treatments generally increased the percent potassium contained in the forage.

The forage from most of the treatments containing phosphorus was lower in percent potassium than the forage from the potassium only or check treatments. The forage from all of the treatments of urea without superphosphate was higher in percent potassium than the forage from the potassium only or check treatments. The forage from the treatments which produced the lowest yield, generally, contained the highest percent potassium.

Calcium: The F values for all treatments and basic treatments were significant at the 1% level. The lowest calcium composition of 1.89% was from the N_2K treatment. The highest calcium composition of 2.43% was from the N_1P_1K treatment. The overall average calcium composition was 0.208%.

The forage from the check treatment contained 0.214% calcium. The N_2, P_1K, N_1P_1, and N_1P_1K treatments were the only treatments to produce forage higher in percent calcium than the check. The forage from the N_1K, P_1K, and N_1P_1K treatments contained a higher percent calcium than did the forage from these same treatments without potassium. At the high rate of nitrogen and/or phosphorus, potassium usually reduced the percent calcium of the forage. Increasing the application rate of the N, P, and AP treatments increased the percent calcium of the forage. The forage from all treatments with potassium and the NP treatment contained a lower percent of calcium at the high rate than the forage from the low rate.

Magnesium: The F values for all treatments and K treatment were significant at the 5% level. The lowest magnesium composition of 0.475% was from the N_2P_2K treatment. The highest magnesium composition of 0.535% was from the AP_1 treatment. The overall average magnesium composition was 0.505%.

The forage from the check treatment contained 0.478% magnesium. The two treatments of the high rate of a complete fertilizer (N_2P_2K and AP_2K) were the only treatments to produce forage which contained a lower percent magnesium than the forage from the check. The application of potassium usually decreased the percent magnesium of the forage when treatments were compared with and without potassium.

Residual Effect of Soil Fertility Treatments on Yield of Sudan Grass, Previous Crop Grown at a Low Soil Moisture:

Lahoma sweet sudan grass was grown in the greenhouse to study the residual value of the soil fertility treatments. The forage yield data of the sudan grass are reported in Table IX. The yields discussed are the average yields of three replications reported as grams of oven dry forage per pot.

The fertility treatments had been applied to a previous crop of Redlan grain sorghum grown at a low soil moisture level. Details of the soil fertility treatments are shown in Table III. The treatment symbols used in the discussion of results are explained on page 22.

There were no statistically significant yield differences among the treatments as indicated by the F values. The range in differences of average yields was 5.67 grams. The lowest average yield of 14.73 grams was from the P_1 treatment. The highest average yield of 20.40 grams was from the N_2 treatment. The overall average yield was 18.09 grams.

The average yield of the check (no fertilizer) treatment was 19.83 grams. The yield of the potassium only treatment was 4.50 grams less than the check yield. The urea and/or superphosphate treatments (N, P, NP) with potassium produced less forage at the low rate and more forage at the high rate than the same treatments without potassium. The ammonium phosphate treatments at both rates with potassium (AP_1K and AP_2K) produced less forage than the same treatments without potassium.

TABLE IX: RESIDUAL EFFECTS OF VARIOUS SOIL FERTILITY TREATMENTS ON THE YIELD OF LAHOMA SWEET SUDAN GRASS FORAGE, PORT SILT LOAM, GREENHOUSE EXPERIMENTS, STILLWATER, 1958.

Low Soil Moisture Level

Previous Treat-ment 1/	Without Potassium I	II	III	Ave.	With Potassium I	II	III	Ave.
	Grams oven dry forage per pot							
Check	21.6	18.1	19.8	19.83	16.2	13.9	15.9	15.33
N_1	13.0	16.4	20.4	16.60	24.0	18.7	16.5	19.73
N_2	21.7	16.8	22.7	20.40	20.8	20.6	17.6	19.67
P_1	11.0	18.0	15.2	14.73	13.0	15.0	16.5	14.83
P_2	22.6	16.6	17.0	18.73	19.9	12.2	18.1	16.73
N_1P_1	14.8	17.0	18.7	16.63	19.0	21.9	19.4	20.10
N_2P_2	20.9	23.2	16.0	20.03	19.0	13.6	17.2	16.60
AP_1	20.1	18.7	17.3	18.70	15.3	17.7	19.4	17.47
AP_2	21.6	18.8	18.9	19.77	19.5	19.1	20.5	19.70
Average				18.38				17.80

Standard Error of Mean=1.537 C.V.=14.70% Treatment F Value (not significant)

High Soil Moisture Level

Previous Treat-ment 1/	Without Potassium I	II	III	Ave.	With Potassium I	II	III	Ave.
	Grams oven dry forage per pot							
Check	16.4	17.4	12.5	15.43	12.3	20.3	12.2	14.93
N_1	23.0	22.7	13.4	19.70	11.5	10.2	18.9	13.53
N_2	16.6	15.2	22.9	18.23	18.1	19.3	19.5	18.91
P_1	14.9	15.4	13.3	14.53	24.1	11.7	13.1	16.30
P_2	13.2	12.7	14.7	13.53	17.0	24.4	12.8	18.07
N_1P_1	17.7	13.3	13.8	14.93	15.8	13.8	20.1	16.57
N_2P_2	16.9	12.9	15.1	14.97	17.0	19.0	15.0	15.83
AP_1	21.8	11.8	21.9	18.50	13.6	12.4	14.6	13.53
AP_2	19.3	14.7	17.9	17.30	20.3	17.3	14.1	17.23
Average				16.35				16.01

Standard Error of Mean=2.219 C.V.=23.66% Treatment F Value (not significant)

1/ See Table III for details of greenhouse experiment.

The N_1P_1K, N_2P_2, and N_2 treatments were the only treatments to produce more forage than the check. The two treatments of the low rate of superphosphate without urea (P_1 and P_1K) produced the two lowest yields. The ammonium phosphate treatments had a greater residual value as indicated by yield than did the superphosphate without urea treatments.

The yields from the AP_1 and AP_2K treatments were higher than the yields from the N_1P_1 and N_2P_2K treatments. The N_1P_1K and N_2P_2 treatments produced higher yields than the AP_1K and AP_2 treatments. The sudan grass appeared to respond more to the nitrogen treatments and less to the phosphorus treatments than did the grain sorghum.

Residual Effect of Soil Fertility Treatments on Yield of Sudan Grass, Previous Crop Grown at a High Soil Moisture:

Lahoma sweet sudan grass was grown in the greenhouse to study the residual value of the soil fertility treatments which had previously been applied to a crop of Redlan grain sorghum grown at a high level of soil moisture. Details of the soil fertility treatments are shown in Table III. The treatment symbols used in the discussion of results are explained on page 22. The forage yield data of the sudan grass are reported in Table IX. The yields discussed are the average yields of three replications reported as grams of oven dry forage per pot.

The F values for treatments indicated that there were no statistically significant yield differences between the treatments. The coefficient of variation of 23.66% indicated that the individual variation within treatments was high. The range in differences of average yields was 6.17 grams. The lowest yields of 13.53 grams were produced from the AP_1K, N_1K, and P_2 treatments. The highest average yield of 19.70 grams was produced from the N_1 treatment. The overall average yield was 16.18 grams.

The average yield of the check (no fertilizer) treatment was 15.43 grams. The average yield of the potassium only treatment was 0.50 grams less than the check. The treatments containing superphosphate and potassium (NPK and PK) produced higher yields than the same treatments without potassium. The N_1K and AP_1K treatments produced more forage than the N_1 and AP_1 treatments. The N_2P_2K and AP_2K treatments produced less forage than the N_2P_2 and AP_2 treatments. The high application rate of the treatments with potassium usually produced more forage than the low rate with potassium. The high rate without potassium, however, usually produced less forage than the low rate without potassium.

The urea treatments alone usually produced higher yields than the ammonium phosphate or the urea plus superphosphate treatments. The N_2K treatment produced the most forage of any treatment with potassium, but the N_1K treatment produced one of the lowest yields. The ammonium phosphate appeared to have a greater residual effect on the yield of the sudan than the superphosphate treatments with or without urea.

V SUMMARY AND CONCLUSIONS

The principal objective of the field and greenhouse experiments was to compare ammonium phosphate (13-39-0) to superphosphate (20% P_2O_5) with and without urea (45% N) as to relative effectiveness and phosphorus availability. Potassium was included in half of the treatments to study the need for nutrient element balance.

The field experiments were conducted on a Port silt loam at the Lake Carl Blackwell agronomy station. The experiments were set up in a split-plot design with three replications. Potassium levels were the main plots with seven basic treatments randomized in each main plot. The grain yield of Concho wheat and the forage yield of Lahoma sweet sudan grass were the criteria for determining the effects of the soil fertility treatments.

Results and conclusions from the field experiments may be summarized as follows:

1. The highest yield in both experiments was from the high rate of ammonium phosphate with potassium. The second highest yields were from the high rate of superphosphate and urea with potassium.
2. Ammonium phosphate treatments generally produced higher yields than the superphosphate without urea treatments. The superphosphate and urea treatments usually produced equal or higher yields than the ammonium phosphate treatments.

3. The highest yields were from the high rate of a complete fertilizer (nitrogen, phosphorus, and potassium) indicating the need for nutrient element balance to produce optimum yields.

The four greenhouse experiments were grown on Port silt loam. There was a treatment factorial of nine basic treatments and two potassium levels. The objective of the first two studies was to determine the effect of the soil fertility treatments on the yield and chemical composition of Redlan grain sorghum forage, at different soil moisture levels. The objective of the second two studies was to measure the residual effects of the soil fertility treatments from the first two studies on the yield of Lahoma sweet sudan grass forage.

Results and conclusions from the greenhouse experiments may be summarized as follows:

1. The highest yields from both the high and low soil moisture experiments were produced by the ammonium phosphate treatments.
2. The ammonium phosphate treatments usually produced higher initial yields than the superphosphate with or without urea treatments.
3. There was the indication of the need of a highly water soluble phosphorus source with the high rates of phosphorus application with potassium, especially at the low soil moisture level.
4. Potassium fertilization was not necessary to obtain the highest yields from either soil moisture levels.
5. The highest percentages of nitrogen were obtained in forage from the highest rates of nitrogen application, and the highest percentages of phosphorus were obtained from forage produced with the

highest rates of phosphorus application. Percentages of potassium were usually higher from the treatments which contained potassium.

6. The highest yields of forage usually contained the lowest percent of calcium. Potassium fertilization usually decreased the percent magnesium of the forage.

7. The residual crop of Lahoma sweet sudan grass responded more to the urea treatments and less to the phosphorus treatments than did the previous grain sorghum crop.

8. The ammonium phosphate treatments usually had a higher residual value than the superphosphate treatments with or without urea at the high moisture level.

9. At the low soil moisture level the ammonium phosphate treatments had a higher residual value than the superphosphate treatments without urea. The superphosphate and urea treatments had a higher residual value than the ammonium phosphate treatments.

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VII APPENDIX

TABLE X: THE PROFILE DESCRIPTION OF PORT SILT LOAM USED IN FIELD AND GREENHOUSE EXPERIMENTS.

The following profile description was made on the location of the soil fertility field experiment at the Lake Carl Blackwell station. The site is a rarely inundated floodplain of Stillwater Creek. The landscape is weakly convex with about a one percent slope toward the creek. This is an Alluvial Soil formed over red beds. 1/

A_{1p}	0-6"	Light reddish-brown (5YR 6/4; 4/3, m) silt loam; weak fine granular; friable; pH 6.4; a few fine pores; grades to the horizon below.
A_1	6-12"	Reddish-brown (5YR 5/4; 5/2, m) silt loam; moderate medium granular; friable; pH 6.6; grades to horizon below.
A-C	12-20"	Reddish-brown (3.5YR 4/4; 3/4, m) heavy silt loam; moderate medium granular; friable; permeable; pH 6.9; grades to horizon below.
C_1	20-48"	Reddish-brown (2.5YR 5/4; 4/2, m) light clay loam; moderate to fine medium granular; friable; porous and permeable; pH 7.7; rests on the horizon below.
C_2	48-60"	Red (2.5YR 5/6; 4/6, m) silty clay loam; moderate to medium subangular blocky; very firm; pH 8.1; distinctly harder and more clayey than the horizons above.

1/ Profile description furnished by H. M. Galloway, formerly soil scientist with Oklahoma State University and Soil Conservation Service.

TABLE XI: MULTIPLE RANGE TEST: EFFECT OF VARIOUS SOIL FERTILITY TREATMENTS ON THE NITROGEN, PHOSPHORUS, POTASSIUM, CALCIUM, AND MAGNESIUM COMPOSITION OF REDLAN GRAIN SORGHUM FORAGE, LOW MOISTURE LEVEL, PORT SILT LOAM, GREENHOUSE EXPERIMENT, STILLWATER, 1958.

Percent Nitrogen
(S_m=47.93 x 10^{-3})
(N_2=87 1% level)

Treatment	Mean 1/
P_1	1.88
P_1K	1.89
P_2	1.89
Check	1.91
K	1.94
N_1P	1.94
P_2K	1.95
N_2P_2K	1.97
AP_1	1.99
AP_1K	2.01
N_1	2.05
N_2	2.06
N_1K	2.07
N_1P_1K	2.07
AP_2K	2.08
AP_2	2.11
N_2K	2.12
N_2P_2	2.13

Percent Phosphorus
(S_m=11.44 x 10^{-3})
(N_2=87 1% level)

Treatment	Mean 1/
P_1	0.201
Check	0.205
K	0.205
P_1K	0.209
N_2	0.211
N_2K	0.223
AP_1	0.223
AP_1K	0.223
N_1P_1K	0.224
N_1	0.226
N_1K	0.229
N_1P_1	0.235
N_2P_2K	0.267
P_2	0.292
N_2P_2	0.296
P_2K	0.320
AP_2K	0.337
AP_2	0.361

TABLE XI: (Continued)

Percent Potassium (S_m=66.08 x 10^{-3}) (N_2=87 1% level)

Treatment	Mean 1/
AP_1	2.74
P_1	2.79
P_2	2.85
AP_2	2.85
AP_1K	2.90
N_2P_2K	2.90
N_1	3.01
N_1P_1K	3.06
N_2K	3.08
N_2P_2	3.10
P_1K	3.11
Check	3.12
N_2	3.12
N_1K	3.14
AP_2K	3.17
N_1P_1	3.18
P_2K	3.18
K	3.21

Percent Calcium (S_m=8.28 x 10^{-3}) (N_2=87 1% level)

Treatment	Mean 1/
AP_2K	0.250
P_2K	0.254
N_1K	0.263
P_2	0.269
N_1P_1	0.269
AP_2	0.272
N_2	0.272
N_2P_2K	0.274
P_1	0.275
K	0.279
N_2P_2	0.281
N_1	0.282
P_1K	0.283
Check	0.285
AP_1K	0.285
AP_1	0.286
N_2K	0.292
N_1P_1K	0.296

TABLE XI: (Continued)

Percent Magnesium
(S_m=13.21 x 10^{-3})
(N_2=87 1% level)

Treatment	Mean 1/
P_2K	0.508
AP_2K	0.523
P_1	0.528
N_2P_2K	0.533
N_2K	0.537
Check	0.537
P_2	0.540
K	0.545
N_1K	0.545
N_1	0.547
AP_1K	0.547
AP_2	0.555
N_2	0.558
P_1K	0.563
N_1P_1	0.570
N_1P_1K	0.572
AP_1	0.582
N_2P_2	0.590

1/ Mean of six analyses (3 replications x 2 subsamples)

Note: Any two means not scored by the same line are significantly different. Any two means scored by the same line are not significantly different.

TABLE XII: MULTIPLE RANGE TEST: EFFECT OF VARIOUS SOIL FERTILITY TREATMENTS ON THE NITROGEN, PHOSPHORUS, POTASSIUM, CALCIUM, AND MAGNESIUM COMPOSITION OF REDLAN GRAIN SORGHUM FORAGE, HIGH MOISTURE LEVEL, PORT SILT LOAM, GREENHOUSE EXPERIMENT, STILLWATER, 1958.

Percent Nitrogen
(S_m=115.80 x 10^{-3})
(N_2=87 1% level)

Treatment	Mean 1/
AP_1K	1.59
P_2	1.66
P_1K	1.68
N_2P_2K	1.74
P_1	1.76
AP_2K	1.79
N_2K	1.83
AP_1	1.84
K	1.87
P_2K	1.89
AP_2	1.89
N_1P_1	1.93
Check	1.94
N_1P_1K	2.05
N_1	2.10
N_2	2.13
N_1K	2.22
N_2P_2	2.24

Percent Phosphorus
(S_m=12.10 x 10^{-3})
(N_2=87 1% level)

Treatment	Mean 1/
AP_1K	0.220
N_1K	0.222
P_1	0.236
K	0.243
N_1P_1	0.245
Check	0.247
N_1	0.248
N_2K	0.251
N_2	0.251
AP_1	0.252
N_1P_1K	0.255
AP_2K	0.257
P_2	0.265
P_1K	0.279
N_2P_2K	0.286
AP_2	0.286
P_2K	0.293
N_2P_2	0.320

TABLE XII: (Continued)

Percent Potassium
(S_m=47.43 x 10^{-3})
(N_2=87 1% level)

Treatment	Mean 1/
AP_2	2.32
P_2	2.34
AP_1	2.35
AP_1K	2.44
P_2K	2.52
AP_2K	2.55
P_1	2.63
N_1P_1	2.64
N_2P_2K	2.64
Check	2.69
N_1P_1K	2.72
K	2.74
N_1	2.75
N_2	2.76
P_1K	2.77
N_2K	2.79
N_2P_2	2.81
N_1K	2.86

Percent Calcium
(S_m=7.906 x 10^{-3})
(N_2=87 1% level)

Treatment	Mean 1/
N_2K	0.189
N_2P_2K	0.192
N_1	0.197
AP_2K	0.200
P_1	0.200
AP_1	0.202
N_1K	0.203
K	0.203
AP_1K	0.204
P_2	0.205
P_2K	0.207
N_2P_2	0.208
AP_2	0.208
Check	0.214
N_2	0.215
P_1K	0.219
N_1P_1	0.231
N_1P_1K	0.243

TABLE XII: (Continued)

Percent Magnesium
(S_m=14.22 x 10^{-3})
(N_2=87 5% level)

Treatment	Mean 1/
N_2P_2K	0.475
AP_2K	0.478
Check	0.478
P_1K	0.483
N_2K	0.485
K	0.490
P_2K	0.499
N_1	0.500
P_1	0.502
P_2	0.502
AP_2	0.505
AP_1K	0.508
N_1K	0.512
N_2P_2	0.523
N_2	0.525
N_1P_1K	0.525
N_1P_1	0.530
AP_1	0.535

1/ Mean of six analyses (3 replications x 2 subsamples)

Note: Any two means not scored by the same line are significantly different. Any two means scored by the same line are not significantly different.

VITA

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